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(54) **Wave energy conversion apparatus**

(57) In the apparatus wave action produces an oscillating column of water in a tube (1) upstanding from the sea bed to a level above the water surface, entry and exit of water to and from the tube being effected by means of a ring of apertures (2) in the tube just below the water surface, so that the apparatus is responsive to wave action in any direction, and wherein the movement of air in the tube above the oscillating column of water is utilised through a pneumatic control circuit to drive an air turbine connected to an electric generator.

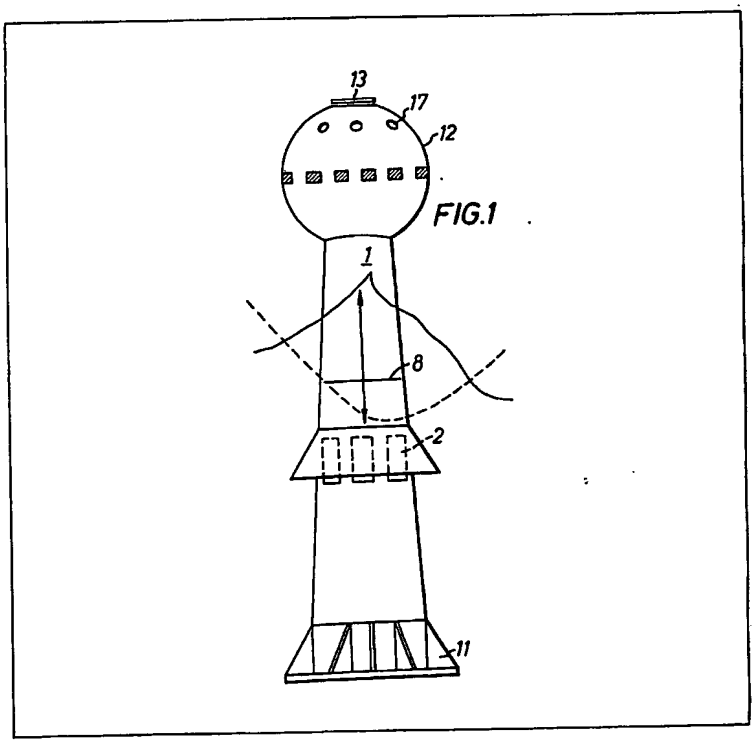

FIG.1

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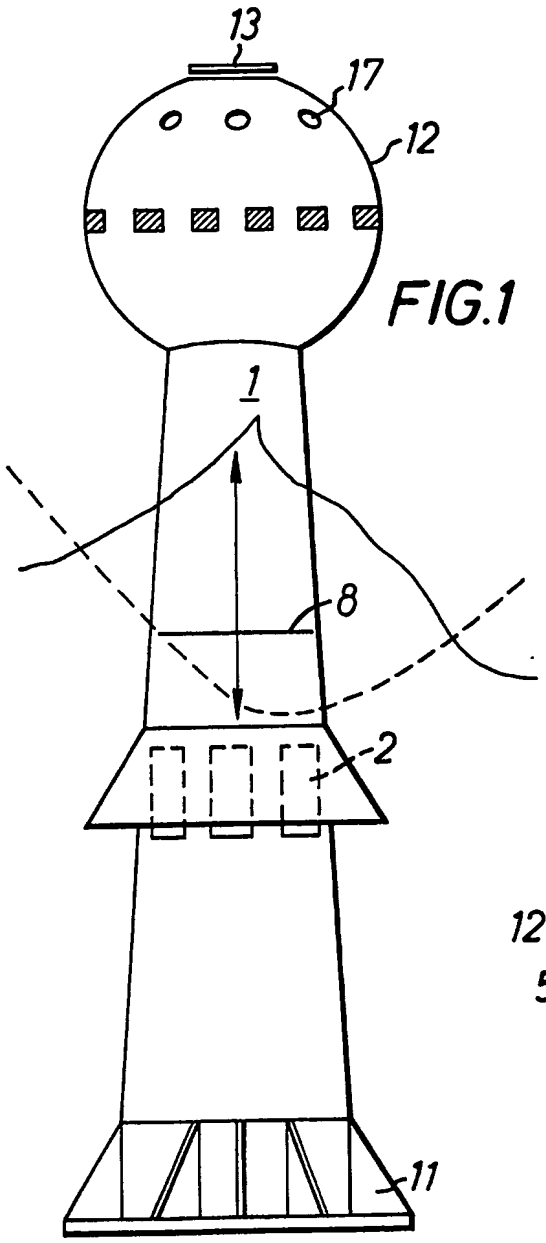

FIG.1

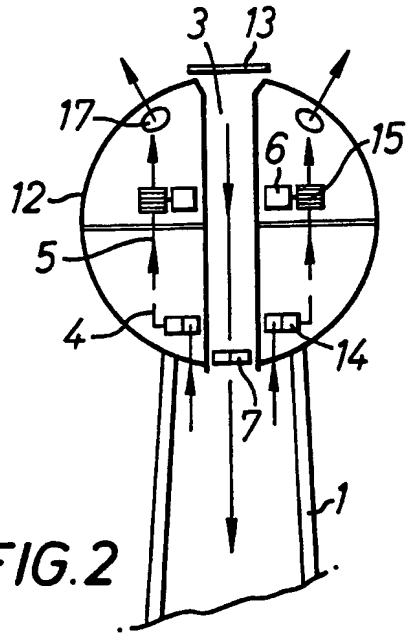

FIG.2

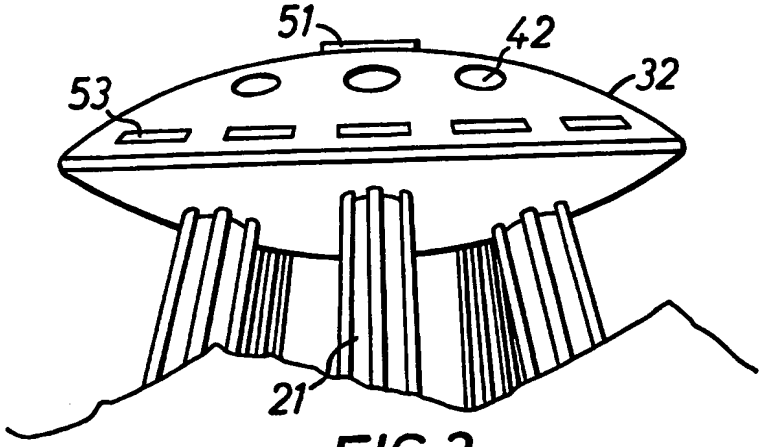

FIG.3

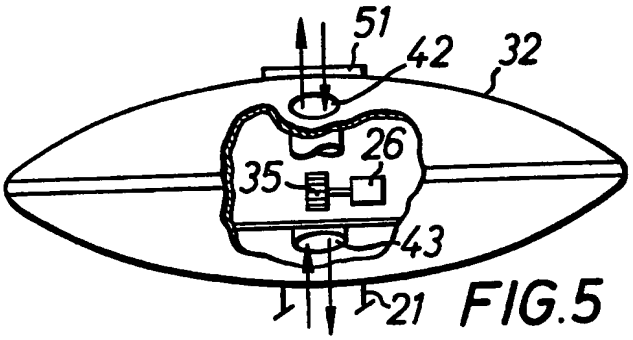

FIG.5

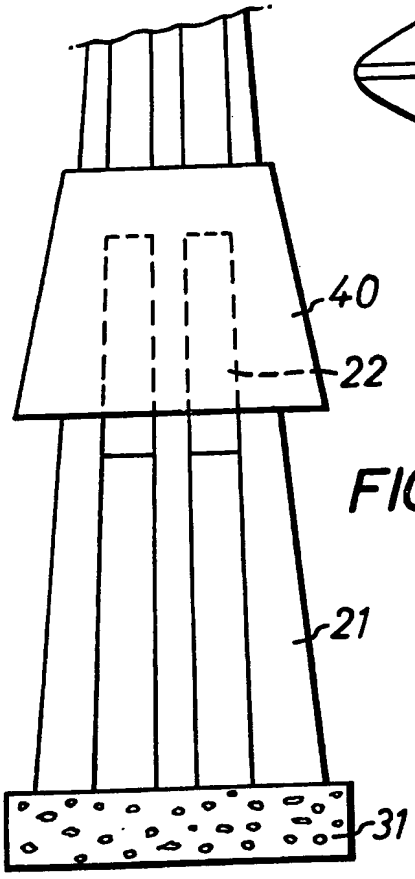

FIG.4

SPECIFICATION

Wave Energy Conversion Apparatus

This invention relates to apparatus for converting wave energy into useful consumable energy.

One known proposal for the utilisation of wave energy comprises a wholly submerged apparatus including a tube in which an annular column of water is caused to oscillate below a volume of trapped air in sympathy with the wave action. A small fraction of water from the water column can be extracted at each oscillation and used to drive a turbine. It is considered that this proposal is not likely to operate satisfactorily in practice and, at best, will operate with only very low efficiency of energy extraction from the waves.

An object of the invention is to provide improved apparatus for wave energy conversion.

Accordingly to the invention, there is provided apparatus for converting wave energy into useful consumable energy, comprising a generally upright hollow tube mounted to a base which, in use of the apparatus, is fixed on the sea bed so that the tube extends upwardly through the water surface at least to a level above the height of the highest anticipated wave crest, the tube being provided with a ring of apertures in its wall, which apertures will be disposed at a level not substantially below the dpeth of the lowest anticipated wave trough, whereby a column of water will oscillate within the tube in sympathy with the wave action, constituting a liquid piston, and energy conversion means mounted to the upper end of the tube, said conversion means comprising an air driven turbine and a pneumatic control system therefore in valved communication with the air space in the tube above the liquid piston.

Preferably, an inverted funnel is mounted around the tube with its lower end at the level of the apertures, thereby to amplify the stroke of the liquid piston relative to the wave height.

The energy conversion means mounted at the upper end of the tube can take various forms. In one arrangement, the pneumatic control system comprises an air reservoir for pressurized air delivered through a non-return valve when the air space is compressed during the upward stroke of the liquid piston, and a passage containing a non-return valve permitting atmospheric air to be drawn into said air space during the downward stroke of the liquid piston. In this arrangement, air is drawn from the reservoir to drive the turbine continuously.

In a preferred arrangement, the pneumatic control system comprises a chamber housing the fan of the air turbine, said chamber having inlet/outlet ports in communication with the air space above the liquid piston and with the atmosphere, whereby air is drawn through the chamber to drive the fan during both the upward and downward strokes of the liquid piston, the system also including a valved loop circuit arranged so that the fan is driven unidirectionally during both said upward and downward piston strokes. This arrangement has the advantage that the oscillating water column is used as a double-acting piston, which effectively doubles the efficiency of energy action from the waves when compared with the first described arrangement.

In practice, it is envisaged that a plurality of tubes will usually be employed, forming part of a unitary structure adapted to be fixed to the sea bed, the upper ends of the tubes supporting a power station platform above the water surface, which platform houses the energy conversion means.

The invention will now be examplified with reference to the accompanying drawings, in which:-

Figure 1 is a diagrammatic elevational view of a single tube arrangement;

Figure 2 is a diagrammatic view, in vertical section, of the platform supported at the uper end of the tube;

Figure 3 is a diagrammatic view of a preferred arrangement, showing the portion of the apparatus above the water surface;

Figure 4 shows the submerged portion of one of the tubes, in the arrangement of Figure 3; and

Figure 5 is a cut-away view of the platform supported at the upper ends of the tubes.

In the arrangement of Figure 1 and 2, the apparatus comprises a hollow tower in the form of a tube 1 upstanding from a base 11 fixed to the sea bed. The tube 1 projects clear above the level of the water to support a platform 12, and is provided with a ring of slit-shaped apertures 2, at a level just below the depth of the lowest anticipated wave trough, also taking into account rise and fall of the general water level due to tides.

When the apparatus is thus installed off shore, a column of water 8 will oscillate in the tube 1 in sympathy with the wave action, as water enters and exits from the apertures 2 in accordance with the changing static head. The oscillating column of water will be produced whatever the direction in which the waves are running.

In accordance with the invention, the oscillating liquid column 8 is used as a liquid piston to compress the air in the tube 1 above the column. The compressed air is utilised in a pneumatic control system to drive an air turbine, which in turn drives an electric generator. The pneumatic control system, the turbine and the generator constitute energy conversion means housed in the platform 12 mounted at the upper end of the tube,

Figure 2 shows an air passage 3 through the platform, said passage being covered by a weather protective cap 13. Air is drawn from the atmosphere through this passage 3, via non-return valves 7, into the upper part of the tube 1 above the liquid piston 8, during downward strokes of said piston. The valves 7 are closed during upward strokes of the liquid piston. At this time, compressed air is delivered, as indicated at 4, from the upper part of the tube 1 through non-return valves 14 into an reservoir (not shown) housed in a lower deck of the platform 12. During downward strokes of the liquid piston 8, the valves 14 are closed.

Pressurized air is supplied continuously from theair reservoir, as indicated at 5, to drive air turbines 15 housed in an upper deck of the platform 12. In turn, the air turbines drive electric generators 6. The reference 17 indicates the exhaust to atmos-

phere from the air turbines 15. The platform 12 thus constitutes a power station from which electrical power can be delivered to the national grid power supply system.

The arrangement shown in Figures 1 and 2 is a modular design. Conveniently, a number of such modular units could be individually fabricated and floated out to an off-shore site, anchored to the sea bed in a suitable formation, and the platforms interconnected by bridges which, in addition to combining the modular units into a single rigid structure, could afford operator access between the units incorporated into the power station.

The above-described arrangement concerns a pneumatic control system deriving energy from the oscillating colum of liquid in a single tube 1, which may be convenient when there is a strong prevalent wave action. However, it is apparent that the power station could be supported at the upper ends of a plurality of smaller diameter tubes operating in parallel, and this may be preferable in a prevalent shorter sea.

Figures 3 and 5 show a modified arrangement employing a plurality of tubes 21, which in this case are formed with stiffening rubs. Clear above the water surface, the tubes support a power station platform 32. Figure 4 shows the portion of one of the tubes 21 below the water surface. This tube 21 extends upwardly from a base 31 (which may be common to all the tubes of the installation) fixed to the sea bed. Just below the level of the lowest anticipated wave trough, the tube 21 is provided with a ring of slit-shaped apertures 22. Around the ring of appertures 22 the tube 21 carries an inverted funnel 40, preferably closed around the tube at its upper end above the level of the ring of apertures. The open lower end of the inverted funnel is disposed only just above the level of the bottom of the apertures, so that the funnel surrounds the apertures over the major part of their height.

In use, an oscillating column of water is produced inside the tube 21, in a manner similar to that described with reference to Figfure 1 and 2. However, the funnel 40 acts under a wave crest to trap additional water, which can only escape through the apertures 22 into the tube 21, thus reinforcing the oscillating water column. the amplitude of oscillation of the water column, which constitutes the stroke of the liquid piston driving the energy conversion means, is therefore amplified compared to the height between wave crests and wave troughs.

The efficiency of energy conversion is also improved, as compared to the arrangement of Figures 1 and 2, by utilising the oscillating water column as a double acting piston. Thus, referring to Figure 5, the platform 32 is cut away to show that part of the energy conversion means relating to a single tube 21, similar means being provided within the platform foreach other tube. The fan 35 of an air turbine is located in a chamber (not shown) which communicates with a pneumatic control circuit, this circuit having an inlet/exhaust port 42 to the atmosphere and an inlet/exhaust port 43 to the air space in the tube 21 above the liquid piston. Air is exhausted from their air space in the tube 21 through the control circuit to the atmosphere during the upward stroke of the liquid piston, and air is drawn from the atmosphere through the control circuit into the air space in the tube during the downward stroke of the liquid piston. The circuit includes a loop incorporating non-return valves, which are arranged in such a manner that the air passing through the control circ uit, during both upward and downward strokes of the liquid piston, passes unidirectionally through the chamber housing the turbine fan 35. The turbine is thus driven unidirectionally under a pulsating air pressure, and is equipped with a fly-wheel (not shown) to ensure that its output shaft, which drives an electric generator 26, is driven continuously at a substantially constant speed.

For completeness, Figure 3 shows the power station platform 32 provided with a helicopter pad 51 affording access for operators, and with station lights 53.

It will be appreciated that various modifications of the above-described arrangements are possible within the spirit and scope of the invention as indicated by the appended claims. More especially, various other forms of pneumatic control may be employed, whereby an air turbine is driven as a result of the movement of air to and from the air space in the tube above the liquid piston constituted by the oscillating column of water.

CLAIMS

1. Apparatus for converting wave energy into useful consumable energy, comprising a generally upright hollow tube mounted to a base which, in use of the apparatus, is fixed on the sea bed so that the tube extends upwardly through the water surface at least to a level above the height of the highest anticipated wave crest, the tube being provided with a ring of apertures in its wall, which apertures will be disposed at a level not substantially below the depth of the lowest anticipated wave trough, whereby a column of water will oscillate within the tube in sympathy with the wave action, constituting a liquid piston, and energy conversion means mounted to the upper end of the tube, said conversion means comprising an air driven turbine and a pneumatic control system therefore in valved communication with the air space in the tube above the liquid piston.

2. Apparatus according to claim 1, including an inverted funnel mounted around the tube with its lower end at the level of the apertures, thereby to amplify the stroke of the liquid piston relative to the wave height.

3. Apparatus according to claim 1 or claim 2, wherein the pneumatic control system comprises an air reservoir for pressurized air delivered through a non-return valve when the air space is compressed during the upward stroke of the liquid piston, and a passage containing a non-return valve permitting atmospheric air to be drawn into said air space during the down ward stroke of the liquid piston.

4. Apparatus according to claim 1 to claim 2, wherein the pneumatic control system comprises a chamber housing the fan of the air turbine, said chamber having inlet/outlet ports in communication

with the air space above the liquid piston and with the atmosphere, whereby air is drawn through the chamber to drive the fan during both the upward and downward strokes of the liquid piston, the system also including a valved loop circuit arranged so that the fan is driven unidirectionally during both said upward and downward piston strokes.

5. Apparatus according to any of claims 1 to 4, including an electric generator driven by the turbine and forming part of the energy conversion means mounted to the top of the tube.

6. Apparatus according to any of claims 1 to 5, comprising a plurality of tubes forming part of a unitary structure adapted to be fixed to the sea bed, the upper ends of the tubes supporting a power station platform above the water surface, which platform houses the energy conversion means.

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